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New York State
Human Health Fact Sheet

Ambient Water Quality Nutrient Values for Protection of Sources of Potable Waters *(Ponded Waters)*

Substances: *Phosphorus* (*total*) and *Chlorophyll a*

Ambient Water Quality Values

Class AA & AA-S: *Phosphorus (total)**:** 12 ug/l; *Chlorophyll *a*: 4 ug/l

Class A & A-S: *Phosphorus (total): 17 ug/l; *Chlorophyll *a*: 5 ug/l

*Remark: applied as growing season mean

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Basis: Oncogenic effects based upon current total trihalomethane (TTHM) maximum contaminant level (MCL)

A. Introduction

Nutrient enrichment is one of the most significant water quality challenges facing New York State. As of 2004, eutrophication represented approximately 27 and 29 percent of use impairments to ponded and flowing water systems in New York State, respectively (NYSDEC, 2004). Eutrophication-related water quality impairments adversely affect a broad spectrum of water uses, including water supply and recreation, and also adversely affect aquatic life. Concerns about cultural eutrophication (human induced enhancement of primary productivity) are not unique to New York, and the issue is widely recognized as a significant water quality concern at the national and international levels. These concerns lead the United States Environmental Protection Agency (USEPA) to initiate a National Nutrient Strategy in 1998 with the goal of assisting all states in the development of numerical nutrient criteria, and this document represents the end result of that process for sources of *ponded potable waters* in New York State.

Historically, nutrients and nutrient-related indices have rarely been thought of in terms of human health concerns. The rare exception to this situation being the role of nitrates in the development of methemoglobinemia or "blue-baby" syndrome. However, over the past decade, or so, a growing body of evidence has emerged linking cultural eutrophication to a number of additional human-health stressors which include disinfection by-products (DBPs), algal toxins, and arsenic – see Figure 1 in Appendix A.

Disinfection By-Products

Disinfection by-products (DBPs) are a group of compounds formed as a result of chemical reactions between natural organic matter (NOM) and certain disinfection agents (e.g., chlorine). The two major classes of DBPs are trihalomethanes (THMs) and haloacetic acids (HAAs). Several of these compounds (e.g., chloroform) are considered to be carcinogenic (ATSDR 1997, USEPA 2006). There is also some evidence linking DBPs to adverse reproductive effects (USEPA, 2006). The link between nutrient enrichment and increased production of DBPs occurs as follows. In many temperate freshwater systems, phosphorus acts as the limiting growth factor for primary production (e.g., the addition of phosphorus results in an increase in primary production within the system). This increase in primary production leads to: (a) an increase in the level of NOM, and (b) a change in the nature of NOM within the system, which heightens the risk for DBP production when the water is subjected to disinfection. The NYSDEC study discussed below was limited to TTHMs - USEPA (2006) defines total trihalomethanes (TTHMs) as the sum of four chlorinated compounds - chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

Algal Toxins

Algal toxins are a group of compounds formed by certain types of cyanobacteria (also referred to as blue-green algae). These compounds are known to cause acute toxicity in a wide variety of animals (including humans) and are suspected of causing some types of cancer (Yu, 1995). The nexus between nutrients (particularly phosphorus) and cyanobacteria is as follows. *First*, in phosphorus limited systems, an increase in phosphorus concentration provides a selective advantage to cyanobacteria due to the ability of some of these organisms to: (a) fix nitrogen from nitrogen gas dissolved in the water column, and (b) control their buoyancy thus enabling them to attain optimal light conditions. *Second*, increased phosphorus concentration can support a greater standing crop of primary producers (be it true algae or cyanobacteria). The algal toxin compounds that have received the most research to date, and that were the focus of the NYSDEC investigation, include microcystin-LR and anatoxin-A.

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Arsenic

Arsenic is known to cause both acute and chronic adverse human health effects. The arsenic levels likely to occur in surface waters are of concern primarily with respect to chronic health issues, with carcinogenicity being principal among them. Arsenic has been linked to cancer of the bladder, lungs, skin, kidney, nasal passages, liver, and prostate (ATSTR, 2000). The link between cultural eutrophication and water column arsenic enrichment is theorized to occur as follows. As discussed above, an increase in phosphorus concentration leads to an increase in primary productivity (algal and cyanobacterial growth). As the resultant primary producer population senesces and settles through the hypolimnion (lower waters), they are consumed by bacteria in the process of cellular respiration leading to consumption of limited oxygen stores in thermally stratified systems which results in depletion of available dissolved oxygen (DO) stores. If DO depletion is extensive it can result in anoxia (and possibly reducing conditions) within hypolimnetic waters and *may* trigger the release of arsenic (and other redox sensitive compounds) from bottom sediments to the overlying hypolimnetic waters.

Disinfection By-Product/Algal Toxin Ponded Water Study and Related Studies

While there is a growing body of evidence linking cultural eutrophication to these human health stressors in *qualitative* terms, there has been less attention given to translating these findings into *quantitative* relationships.

The New York State Department of Environmental Conservation (NYSDEC), in collaboration with investigators from the New York State Department of Health (NYSDOH), Upstate Freshwater Institute (UFI), State University of New York College of Environmental Science and Forestry (SUNY-ESF), and Morgan State University, conducted a study to investigate the relationship between nutrient-related indices and certain human health related indices in an effort to define nutrient criteria protective of ponded potable water sources. The study was funded by the United States Environmental Protection Agency (USEPA) as part of the agency's National Nutrient Criteria Strategy (USEPA, 1998). The study involved the monthly collection of paired water column samples from 21 lakes and reservoirs during the growing season. The systems were distributed throughout New York State, and spanned a relatively broad range of trophic conditions ranging from oligotrophic systems (low primary productivity) to eutrophic systems (high primary productivity) and included systems from several of New York's Level 3 Ecoregions.

In addition to the USEPA funded effort directed toward establishing a link between nutrient enrichment and the human health related indices of DBPs and algal toxins, the NYSDEC has been involved in an independent investigation of the possible linkage between cultural eutrophication and arsenic enrichment in ponded waters. To date, the department has collected samples from approximately 30 systems throughout the state.

Finally, results from a number of relevant independent investigations were considered in an effort to validate and corroborate findings from the NY State investigations.

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B. Derivation of Criteria

The toxicological basis for the criteria developed herein is based upon previous toxicological findings for the three target human health-related indices. In the case of total trihalomethanes and arsenic this is premised on the current maximum contaminant levels (MCLs) as summarized and presented in the Code of Federal Register (40 CFR January 4, 2006, and January 22, 2001, respectively). In the case of microcystins-LR, the toxicological basis for comparison is summarized and presented by the World Health Organization (1998), and is considered a provisional guideline value.

The approach taken to derive appropriate ambient water quality values (AWQVs) is to assess available information for each of the three human-health related indices (THMs, algal toxins, and arsenic), and to determine which of the three indices leads to the most stringent AWQV. This "limiting toxic" approach should arrive at an AWQV that is protective of potable water supply sources with respect to each of the identified stressors. The assessment is based upon findings from two NYSDEC studies, namely the Disinfection By-Product/Algal Toxins Project (DBP-AT Project) and the Statewide Arsenic Investigation, as well as pertinent material from other independent investigations (both peer review literature and technical reports).

Disinfection By-Products

Several assumptions were made in the derivation of nutrient thresholds THMs. *First*, the target nutrient thresholds are designed to attain the current maximum contaminant level (MCL) for TTHMs, presently set at 80 ug/l per the USEPA Stage 2 Disinfectants and Disinfection Byproducts Rule (2006). *Second*, it is assumed that the applicable toxicological evidence as presented in the USEPA Stage 2 Rule in support of the current MCL is adequate for the protection of human health. It should be noted, however, that the current New York State human-health based ambient water quality standard for chloroform (one of the four TTHMs) is considerably lower (7ug/l) than is the MCL for TTHM. The current MCL for TTHMs is deemed the appropriate target value given that the criteria are directed toward protection of public water supply use which, in all instances for ponded surface waters, involves disinfection. *Third*, it is assumed that the nutrient thresholds defined for THMs are sufficient to protect for HAAs. Most comparable studies in the field support this assumption, in that HAA levels generally parallel TTHM levels (references??).

The NYSDEC DBP-AT Study involved the collection of paired ambient water samples that were analyzed for THM Formation Potential (THMFP) and nutrient-related indices. THMFP is commonly used in research investigations to normalize results for the purpose of system comparisons. Study findings offer several lines of evidence in support of the hypothesis that increased primary productivity (or cultural eutrophication) leads to an increase in the generation of THMFP as follows.

1. Marked seasonal THMFP increases were observed in 18 of 21 study systems.

2. A fairly sound relationship was observed between mean trophic status of a given system and the capacity of the system to generate THMFPs (see Figure 2 in Appendix A).

3. A series of fairly robust relationships were observed for THMFP and the various nutrient indices (e.g., total phosphorus and chlorophyll *a*) as well as for dissolved organic carbon (see Figures 3-5 in Appendix A).

These findings are also consistent with a significant body of literature demonstrating a relationship between nutrient enrichment and the risk of increased THMFP production (Palmstrom, et al 1988, Arruda and Fromm 1989, Wardlaw, et al. 1991, Cooke and Kennedy 2001).

Building upon the relationships discussed above, the next step in the criteria development process is to identify AWQVs for the nutrient indices which are protective of potable waters with respect to DBPs. It is important to note, however, that THMFP represents something of a “worst case” scenario in that the analytical protocol is designed to fully exploit the reaction between the available natural organic matter (NOM) and the disinfectant agent. In contrast, water treatment plant (WTP) operators attempt to minimize the generation of TTHMs, and other DBPs, within the context of providing adequate disinfection. Thus, there is a need to extrapolate THMFP findings to actual TTHM conditions occurring within public water supply systems. Thus, there is a need to extrapolate the THMFP findings into something more akin to actual conditions in a water system.

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Several approaches were evaluated to effect this THMFP to TTHM translation. They include both a combined modeling approach as well as a direct comparison between Study THMFP findings and actual WTP TTHM levels. The modeling approach, which was deemed the preferable approach, involved several steps as presented below.

1. Identify a THM simulation model that provides a reasonably accurate simulation of observed THMFP means. A model was identified that successfully simulated observed *mean* THMFP levels. The identified model algorithm is presented below (Rodriguez, 2002).

   $$[TTHM] = 0.044\ (DOC)^{1.030}\ \times\ (time)^{0.262}\ \times\ (pH)^{1.149}\ \times\ (dose)^{0.277}\ \times\ (temp)^{0.968}$$

   Where,

   TTHM = total trihalomethanes as defined by USEPA MCL (ug/l),
   DOC = dissolved organic carbon (mg/l),
   Time = duration of incubation (hours)
   pH = pH during incubation,
   dose = chlorine dose (mg/l),
   temp. = temperature in °C

   Inputting the parameter specifications for the THMFP method (Standard Method specifications for the THMFP analysis include: time = 168 hours (7 days), pH = 7.0, chlorine dose = 5 mg/l, and temperature = 25 °C) into the unmodified simulation model and comparing simulated THMFP means to observed THMFP means, results in an r^2 of 0.78.

2. Use the model identified in Step 1 to run a simulation of "typical", albeit somewhat conservative, water treatment plant (WTP) conditions. Model parameterization for the "typical" WTP were derived as follows. Residence time was set at 72 hours (3 days) based on an USEPA/AWWA Study (2002). Source water pH was set at 7.8 based upon Summers (1996), chlorine dose was set at 1.0 mg/l based upon Summers (1996), and temperature was set at 20°C. The model is run using the maximum contaminant level (MCL) of 80 ug/l, and the algorithm solved for DOC. This resulted in a **DOC = 3.0 mg/l**.

3. The DOC concentration derived in step 2 is then used to identify a threshold THMFP concentration based upon the observed relationship between mean THMFP and mean DOC (see Appendix A Figure 3) and results in a threshold THMFP concentration of 190 ug/l. The relationship developed between DOC and THMFP in this Study is consistent with that derived from a meta-analysis conducted by Chapra, et al. (1997).

4. The THMFP concentration derived in step 3 is then used to derive applicable AWQVs for the nutrient-related indices of phosphorus (total) and chlorophyll *a* - see Appendix A Figures 4 and 5, respectively. This results in phosphorus (total) and chlorophyll *a* concentrations of 12 ug/l and 4 ug/l, respectively.

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The second approach used to extrapolate THMFP findings involved comparing THMFP levels within each of the study systems to actual public water supply (PWS) TTHM measurements. This approach proved problematic due to several factors including: (1) a number of the target public water supply systems used blended sources, (2) the level of treatment between the various water plants varied markedly, and (3) disparities in space and time between ambient sample collection and PWS sample collection, and thus significantly compromised the validity of the comparisons. While a comparison between the ambient THMFP findings and the water purveyor data were not pursued as the primary approach for extrapolation, some findings from that exercise are informative. When systems are grouped based on source water mean total phosphorus levels (either less than or greater than 15 ug/l) there was a fair degree of separation between the two groups (see Appendix A, Figure 6). As shown, the box plot for PWS systems with source waters phosphorus concentrations below 15 ug/l falls nearly entirely below the MCL of 80 ug/l, whereas PWS systems using source water with phosphorus concentrations above 15 ug/l have a median value approaching the MCL with a significant portion of the box plot above the present MCL. It is very probable that the degree of separation between the two groups is muted due to differences in the level of treatment between the categories of systems. In other words, levels of treatment likely parallel the trophic status of the source water, with eutrophic waters undergoing substantially greater levels of treatment than do oligotrophic systems, and suggesting that absent the probable greater levels of treatment, the more eutrophic systems would likely exhibit significantly greater TTHM levels than observed and the level of separation between the two box plots would also be expected to increase.

In summary, findings to date indicate that a phosphorus (total) concentration at or below 12 ug/l and a chlorophyll *a* concentration at or below 4 ug/l are likely protective of human health with respect to TTHMs in most ponded surface water systems in New York State.

Algal Toxins

Study findings for algal toxins are less definitive due to a limited number of analytical detections for algal toxins, however, they do provide some guidance with respect to applicable nutrient thresholds. In addition, findings from a number of other studies appear consistent with findings of this Study.

Study results indicate something of a step function with respect to *maximum* microcystin-LR levels and mean phosphorus (total) and chlorophyll *a* levels, with an apparent break point occurring at a mean phosphorus concentration of approximately 25-30 ug/l and a mean chlorophyll *a* concentration of approximately 8-10 ug/l. These breakpoints delineate the nutrient-related intervals in which system-specific *maximum* microcystins-LR levels approach or exceed the WHO drinking water guidance value of 1 ug/l (WHO 1998). Thus, by comparison, the threshold levels for the various nutrient indices that are deemed reasonably protective with respect to microcystins-LR are *substantially higher* than those for TTHM.

As with the DBP findings, an effort was made to identify comparable studies in an effort to validate findings from the DEC Study. Several studies were identified that appear to support the threshold values identified in the present Study. However, these previous investigation approach the issue from a somewhat different perspective. The *first* study involved a meta-analysis that evaluated the relative probability of experiencing an algal bloom based upon the mean level of chlorophyll *a* present in the system (Walker, 1985). Findings from the Walker study indicate that

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mean chlorophyll *a* concentrations at or below 10 ug/l substantially reduced the likelihood of an extreme or bloom condition. The *second* study involved comparison of mean levels of certain trophic indices (including phosphorus and chlorophyll *a*) to the relative predominance of cyanobacteria taxa (Downing, et al., 2001). The authors conclude that “The risk of Cyanobacteria dominance is only 0–10% between 0 and 30 ug/L of total P, rising abruptly to about 40% between 30 and 70 ug/l…”, suggesting that there is a threshold with respect to the risk of cyanobacteria at or around a total phosphorus concentration of 30 ug/l. They also suggest that a mean chlorophyll *a* concentration of 10 ug/l represents something of a threshold above which the risk of cyanobacteria domination climbs above 10 percent, and is “a known breakpoint where nuisance algae blooms occur at high frequency.” Thus, findings from both of these investigations are consistent with the values identified in the present Study with respect to the risk for bloom conditions and predominance of cyanobacteria, namely, 25-30 ug/l for mean phosphorus (total) and 8-10 ug/l for mean chlorophyll *a* concentration.

To summarize, the phosphorus and chlorophyll *a* levels deemed protective for algal toxins are somewhat higher than those considered protective for DBPs (as represented by THMs). Thus, the AWQVs derived for DBPs are expected to be protective for algal toxins as well.

Arsenic

Findings from the NYSDEC Arsenic Investigation indicate that arsenic levels in the hypolimnetic waters of several eutrophic lakes and reservoirs in New York State are near or above the 10 ug/l MCL for arsenic. Preliminary findings also support the hypothesis that cultural eutrophication and resultant dissolved oxygen depletion are contributory to the observed arsenic enrichment. Preliminary findings suggest that the source of arsenic for most of the target systems is likely of natural origin (native bedrock formations). However, while the source of arsenic is likely natural and the causation of dissolved oxygen depletion in the hypolimnetic waters of a stratified system likely a combination of both natural and anthropogenic factors, it is likely that cultural eutrophication has exacerbated such conditions.

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These findings are generally consistent with the findings of a number of other researchers. For example, in a review of arsenic cycling in freshwater systems, Ferguson and Gavis (1971) suggested that arsenic could move from benthic sediments to the overlying water column under reducing conditions. Aggett and O’Brien (1985) developed a detailed model for arsenic mobility in a thermally stratified lake, and documented the importance of reducing conditions in the release of arsenic in Lake Ohakuri in New Zealand. A number of other researchers have demonstrated the link between eutrophication and arsenic mobility in freshwater lakes (Kuhn and Sigg 1993, Sohrin, et al. 1997, and Senn, et al., 2007).

While the relationship between increasing hypolimnetic arsenic concentrations and cultural eutrophication appears sound, and is consistent with the findings of other researchers, it is not possible at this juncture to define specific threshold levels for the various nutrient indices due to the complexity of both dissolved oxygen and arsenic dynamics within thermally stratified systems. However, the AWQVs derived based on DBP findings would likely substantially reduce the incidence and extent of dissolved oxygen depletion and as a consequence, reduce the occurrence of arsenic enrichment in these systems.

Final Criteria

The derivation of final nutrient criteria is premised on safeguarding potable waters from each of the human health factors listed previously, and, thus, the levels proposed are based upon the most restrictive parameter. This would suggest that the AWQVs identified for DBPs are the most appropriate, albeit, with the caveat that arsenic-based thresholds can not be derived at this juncture.

It was deemed appropriate to establish ambient criteria for both phosphorus (total) and chlorophyll *a*. The reason for deriving criteria for phosphorus is premised on an extensive body of literature indicating that phosphorus is the limiting nutrient (or causal variable) for primary productivity in most temperate, freshwater, ponded waters. The rationale behind setting criteria for chlorophyll *a* is that it provides the most widely accepted measure of primary productivity (response variable) within freshwater ponded systems.

It is appropriate to derive distinct AWQVs for different use class categories of ponded surface waters carrying best usage of source of potable water supply, due to differing level of expected treatment inherent in the specific use classes. The four applicable use class categories include AA, AA-S, A, and A-S. Ponded water supply sources carrying water use classes AA or AA-S will be subject to the more stringent AWQVs given that these waters are expected to meet applicable drinking water standards after only disinfection, whereas, ponded water supply source waters carrying water use classes A or A-S will be subject to somewhat less stringent AWQVs given that they are expected to meet applicable drinking water standards following "conventional" water treatment – see applicable language below.

It should also be noted that while both designed use categories (Class AA & AA-S, and Class A & A-S) include a caveat relating to "naturally present impurities", this was not deemed applicable for situations of cultural eutrophication, which, by definition are driven by anthropogenic-driven processes.

Class AA and Class AA-S

Class AA and AA-S Criteria

*Phosphorus (total): 12 ug/l (0.012 mg/l)

*Chlorophyll *a*: 4 ug/l (0.004 mg/l)

*Remark: applied as growing season mean

The most stringent AWQVs are applicable to water use class AA and AA-S, given that these systems are required to meet applicable drinking water standards following only disinfection. The applicable water use classification language for *Class AA* waters states:

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"*This classification may be given to those waters that, if subjected to approved disinfection treatment, with additional treatment if necessary to remove naturally present impurities, meet or will meet New York State Department of Health drinking water standards and are or will be considered safe and satisfactory for drinking water purposes*."

The applicable water use classification language for class AA-S waters does not include reference to disinfection. However, given that all surface water supply sources in New York State are required to disinfect, it is deemed appropriate to include Class AA-S within this category.

Class A and A-S

Class A and A-S Criteria

*Phosphorus (total) <= 17 ug/l (0.017 mg/l)

*Chlorophyll a <= 5 ug/l (0.005 mg/l)

*Remark: applied as growing season mean

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Somewhat less restrictive AWQVs are applicable to water use Class A and A-S due to regulatory language indicating that these systems are required to meet applicable drinking water standards following conventional water treatment measures.

The regulatory language for Class *A* waters is as follows.

"*This classification may be given to those waters that, if subjected to approved treatment equal to coagulation, sedimentation, filtration and disinfection, with additional treatment if necessary to reduce naturally present impurities, meet or will meet New York State Department of Health drinking water standards and are or will be considered safe and satisfactory for drinking water purposes.*"

The regulatory language for Class A-S waters is as follows.

"*This classification may be given to those international boundary waters that, if subjected to approved treatment, equal to coagulation, sedimentation, filtration and disinfection with additional treatment, if necessary, to reduce naturally present impurities, meet or will meet New York State Department of Health drinking water standards and are or will be considered safe and satisfactory for drinking water purposes*."

In light of the expected reductions in DOC due to conventional water treatment methods, and the caveats regarding diminished removal efficiency with increasing eutrophication, it was deemed appropriate to assume a somewhat conservative DOC removal efficiency of 10% - note, this is a reduction in DOC, not in phosphorus or chlorophyll. Thus, using a DOC of 3.3 mg/l (derived based on a DOC removal efficiency of 10%: 3.3 – 0.3 = DOC-threshold of 3.0 mg/l), this equates to THMFP of 220 ug/l, which in turn equates to a phosphorus (total) concentration of 17 ug/l and chlorophyll *a* concentration of 5.5 ug/l (reduced to 5.0 ug/l for the purposes of simplification).

Waters with Site-Specific Nutrient Criteria

A number of ponded water supply source waters within New York State have “site-specific” numerical nutrient criteria developed by other jurisdictions. For example, site-specific nutrient criteria are presently in place for Lake Ontario, Lake Erie, Lake Champlain, and the New York City Reservoir System. In each of these instances, numerical nutrient criteria have been established for phosphorus but not for chlorophyll *a*. Application of the present criteria to these waters will depend upon several factors. Where site-specific criteria are set at a level lower than the criteria set herein, the site-specific criteria will be deemed acceptable. Where site-specific criteria are set higher than the criteria set herein a determination will need to be made as to the rationale the site-specific criteria. If an acceptable rationale is provided for the site-specific criteria, then the criteria will be considered acceptable. Acceptable reasons for designation of higher criteria level include: (a) evidence of dystrophy, or the lack of a linkage between causal and response variables; and (b) evidence of naturally elevated phosphorus concentrations.

C. Discussion of Supporting Material

Basis for Conservative Approach

The AWQVs derived above are relatively conservative with respect to the protection of potable water supply sources from the effects of cultural eutrophication. There are a number of lines of evidence to suggest that such a relatively conservative approach is warranted.

For example, Palmstrom, et al. (1988) provides an extensive discussion of the direct and indirect links between cultural eutrophication and increased THM production. These include the tendency for eutrophication to cause an increase in epilimnetic pH which can increase the production of THMs directly, as well as leading to an increase in the prevalence of cyanobacteria which have a greater propensity to produce THMs, and also produce toxins. In addition, the authors discuss the potential to increase water column phosphorus concentrations as a result of dissolved oxygen depletion and the release of phosphorus from benthic sediments. They also discuss certain water plant operational factors that may exacerbate THM production due to increasing trophic state, such as increased chlorine dosage in response to taste and odor issues.

Some additional factors that suggest the need for a relatively conservative approach are as follows. *First*, a number of researchers have determined that water treatment efficacy is compromised by cultural eutrophication. For example, Cheng and Chi (2003) state that “…changes in the quality of water after eutrophication make the treatment of drinking water more difficult.” *Second*, DBPs (ATSDR 1997, USEPA 2006) and arsenic (ATSDR 2000) are both probable human carcinogens and preliminary findings suggest possible oncologic effects for certain types of algal toxins (Yu, 1995). Thus, the potential exists for additive effects for these substances with respect to carcinogenicity. *Third*, global climate change is likely to exacerbate conditions by extending the growing season and, consequently, the period of thermal stratification which would result in the following: (a) increase the period of elevated precursor production by extending the growing season; (b) increase the production of DBPs by increasing

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water temperatures; (c) favor the growth of cyanobacteria which would exacerbate both production of DBPs and algal toxins; and (d) extend the duration and magnitude of dissolved oxygen depletion, thereby enhancing the possible release of redox sensitive constituents (e.g., phosphorus and arsenic). Several studies have expressed such concerns about the effects of climate change on water quality (Magnuson, et al. 1997, IJC 2003). Finally, one additional factor that supports the need for a more stringent approach is the relatively recent release of National Primary Drinking Water Regulations: Stage II Disinfectants Disinfection Byproducts Rule (CFR, January 4, 2006) which calls for meeting MCLs at compliance monitoring sites with the highest DBP levels as defined by an Initial Distribution System Evaluation.

Application of Criteria

The nutrient criteria presented above are applicable to all ponded freshwater systems carrying the aforementioned classifications, and are to be applied as growing season mean concentrations from the photic zone of a lake or reservoir. The criteria are applicable to all portions of the system beyond the mixing zones of permitted discharges.

The criteria are to be applied in combination, with chlorophyll *a* taking primacy. The various scenarios and regulatory responses are as follows.

a. In those instances in which both chlorophyll *a* and phosphorus (total) exceed the relevant criteria by 10 percent or more the system will be deemed to contravene the criteria.
b. In those instances in which chlorophyll *a* levels exceed the relevant criteria by 10 percent or greater, but phosphorus (total) is below the criteria, the system will be deemed to contravene the criteria, however, it will be important to explore the relationship between the causal and response variables in greater detail to determine the appropriate numerical target for the causal variable.
c. In those instances in which phosphorus (total) levels are above the criteria by more than 10 percent, but chlorophyll *a* levels are below the relevant criteria, the systems will not be deemed to contravene the criteria, however, it would be prudent for regulators to confirm that chlorophyll *a* levels remain below the criteria and to further explore the relationship between causal and response variables.
d. In those instances in which a ponded system is within +/- 10 percent of the relevant criteria, the system will be put on a *watch list* and will be subject to additional monitoring and management action in an effort to confirm current conditions and trends and to prevent and/or reverse any further deterioration of trophic conditions.

The reasoning for using a “buffer” (+/- 10 percent) is as follows. Most ponded freshwater systems exhibit substantial inter-annual variability in trophic indices, therefore, it is likely that a number of systems will exhibit conditions that fluctuate both above and below the criteria from year to year. Furthermore, there is some level of uncertainty inherent in the established regression relationships, as demonstrated by the confidence intervals presented on the curves. Therefore, given the level of effort and costs involved in a full TMDL, it is deemed prudent to offer a less stringent and more flexible process for managing these marginal systems. Finally, it is well established that the prevention of water quality degradation is often substantially more economical than is restoration, thus, the process of alerting and mobilizing community action prior to reaching impaired conditions represents a more efficient investment with respect to

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environmental stewardship. The systems that fall within the buffer zone would then be placed on a watch list and information/guidance would be offered to the watershed community to include: (a) the current condition of the resource, (b) implications of further declines in water quality with respect to reductions in drinking water quality, regulatory consequences (e.g., 303(d) listing and total maximum daily load development), and (c) recommended actions to curtail and possibly reverse declines in water quality.

Finally, it should also be noted that the proposed process is somewhat different than that recommended by USEPA. USEPA (2000) states "A rule of compliance is then established for the criteria that have been selected for each indicator variable. The four initial variables include two causal variables (TN and TP) and two response variables (chlorophyll *a* and Secchi depth or a similar indicator of turbidity). Failure to meet either of the causal criteria should be sufficient to prompt action. However, if the causal criteria are met, but some combination of response criteria are not met, then there should be some form of decision making protocol to resolve the question of whether the lake in question meets the nutrient criteria or not." Whereas, USEPA appears to consider the causal variable(s) to take president, it was deemed appropriate to designate chlorophyll *a* to be the primary concern, even though it represents the response variable, given that it is variable linked most directly to the designated use.

Caveats/Limitations

While the nutrient criteria developed above are believed protective of most potable water supply lakes and reservoirs in New York State with respect to the generation of disinfection by-products, algal toxins, and arsenic enrichment, several caveats are warranted.

First, with respect to disinfection by-products, it is probable that there are systems within the state that will experience elevated levels of disinfection by-products in spite of meeting the aforementioned nutrient criteria, due to the fact that they are dominated by allochthonous production (organic material of watershed origin). *Second*, there may be instances in which algal toxins approach the WHO criteria due to conditions that may favor cyanobacteria dominance and proliferation (e.g., Zebra mussels), as well as enhanced production of toxins. *Third*, there may be instances when arsenic levels exceed the current MCL due to site specific conditions such as system morphometry or geology. In each of these instances, it will necessary to evaluate conditions on a case by case basis, and give consideration to the derivation of site-specific criteria as necessary.

Context of Criteria

Several jurisdictions have derived, or are in the process of deriving, numerical nutrient criteria supportive of potable water supply use. The criteria have included numerical values for either phosphorus (total) or chlorophyll *a*, and are derived based on several different factors. The following table provides a summary of the various nutrient criteria for potable water usage in other locations. As can be seen from the table, the criteria from the various jurisdictions differ somewhat from the criteria values presented here with some of the values being lower and some higher then the NY State criteria.

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Jurisdiction	Numerical Criteria		Basis for Criteria
	Phosphorus (total)	Chlorophyll a	
British Columbia	10	na	Bloom potential
New York City *	15 (20)	na	Bloom potential, taste & odor
State of Oklahoma	na	10	Bloom potential

All values in units of ug/l (or ppb)
* Pertains to West of Hudson reservoirs. TP = 15 ug/l is applicable to terminal reservoirs while 20 ug/l is applicable to upland reservoirs

In addition to the regulatory criteria listed above for other jurisdictions, there are a few investigations and/or reports that provide recommendations for numerical nutrient thresholds. For example, Arruda and Fromm (1989) recommended a chlorophyll *a* threshold of 5 ug/l to limit TTHM production below the TTHM drinking water standard at the time of 100 ug/l. This is remarkably consistent with the criteria derived here, particularly given the subsequent reduction in the MCL for TTHMs (currently 80 ug/l), and the assumption that the reduction in the regulatory target would result in a comparable reduction in the recommended chlorophyll *a* threshold.

Another set of recommendations relevant to this discussion, albeit not as explicit as those from the Arruda and Fromm investigation, can be extracted from the USEPA Nutrient Criteria Technical Guidance Manual for Lakes and Reservoirs (2000). Relevant excerpts from this document are as follows:

(a) "*Limnologists and lake managers have developed a general consensus about freshwater lake responses to nutrient additions, that essentially an ambient total phosphorus (TP) concentration of greater than about 0.01 mg/L and or a total nitrogen (TN) of about 0.15 mg/L is likely to predict blue-green algal bloom problems during the growing season.*",

(b) In Table 7.1 and in reference to a TSI = 40-50 and TP = 12-24 ug/l, the authors state that there is an "*increasing probability of hypolimnetic anoxia…THM precursors exceed 0.1 mg/l*", and

(c) "*Several points along the trophic state continuum are relevant for drinking water supplies. The first is at a trophic state index (TSI) of 40 to 50, when the hypolimnion becomes anoxic. This is when iron and manganese problems would first be evident. At a TSI of 50, the turbidity of the water might be expected to exceed 1 NTU, and filtration of the raw water would become necessary. It is at a TSI of 50 that Arruda (1988) found that trihalomethane concentrations in the finished water exceed 100 mg/L in some Kansas treatment plants. Therefore, it is at this trophic state that extra measures or changes in the treatment process are necessary to control taste and odor without increasing the chlorine dose.*"

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Appendix A

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Figure 1: Eutrophication Cascade: The theoretical sequence of events for the "eutrophication cascade" is as follows (moving clockwise from upper left): *increased phosphorus loading* leads to increased *primary production*; increases primary production results in increased levels of *natural organic matter* (NOM); increased NOM leads to *increased production of disinfection by-products* (DBPs) as well as increased *consumption of dissolved oxygen* (DO) due to bacteriological respiration; DO depletion in the hypolimnetic waters of *thermally stratified systems* can lead to *anoxia* and *reducing conditions* which can result in *release of phosphorus* and *arsenic* from the bottom sediments to the overlying water; and the *increased availability of phosphorus* can lead to a *selective advantage* and *increased growth* of *cyanobacteria* with subsequent *increases in "algal toxins*".

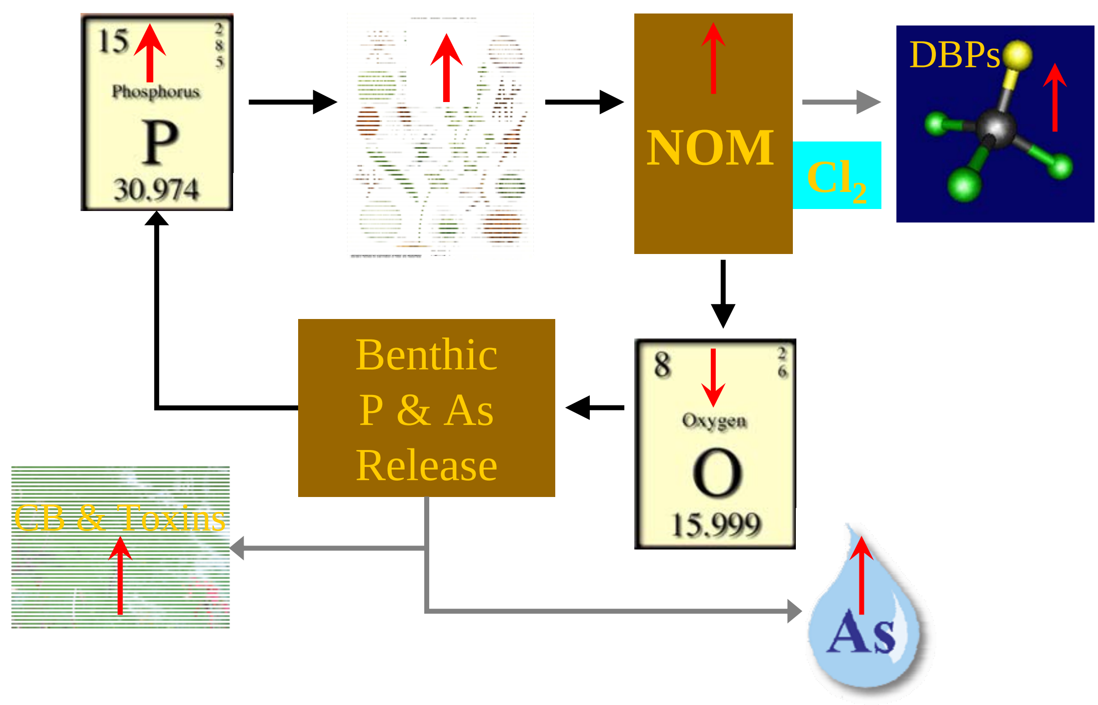

Figure 2: System epilimnetic THMFP aligned by increasing mean chlorophyll a levels

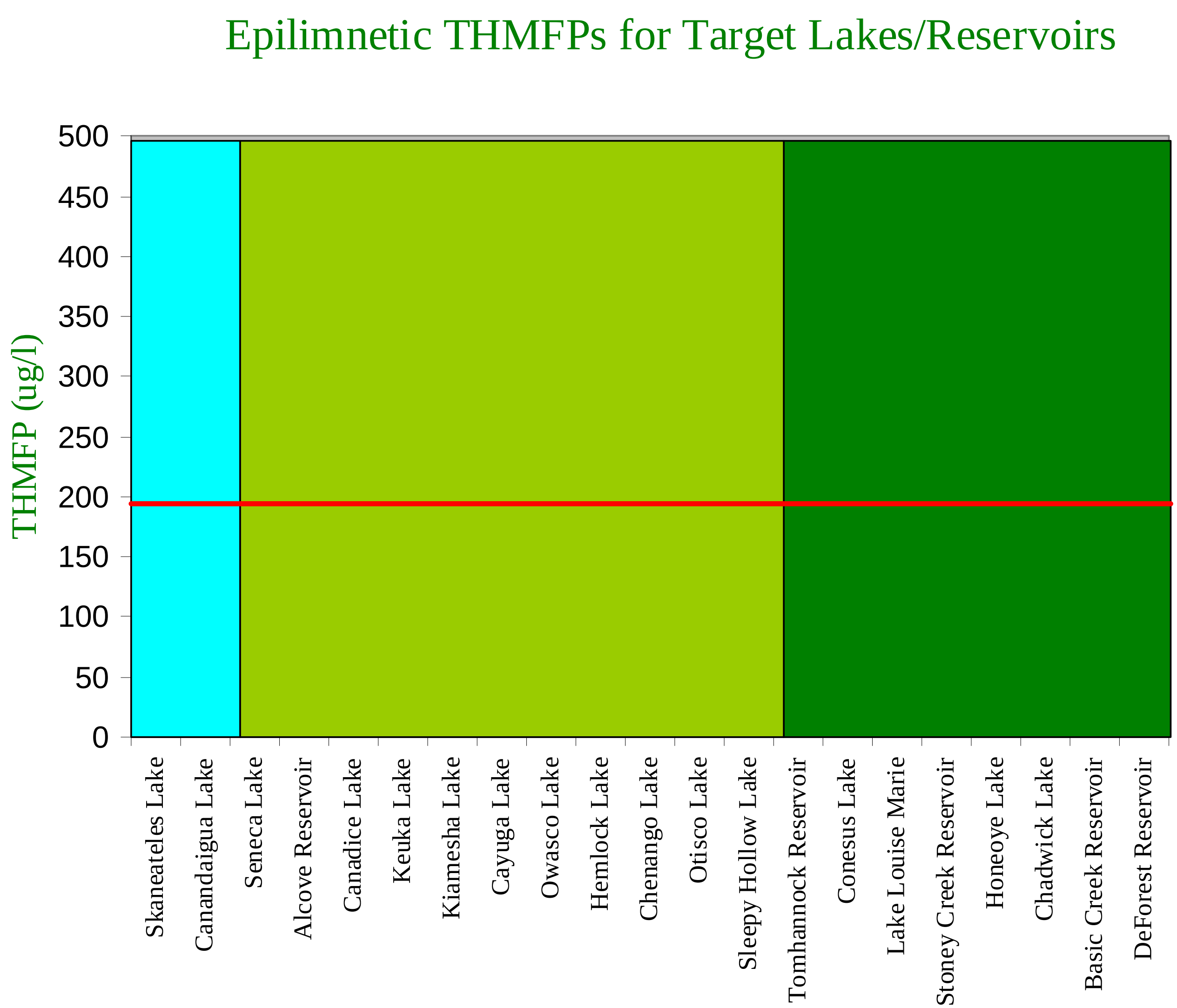

Figure 3: Mean epilimnetic THMFP and mean epilimnetic dissolved organic carbon

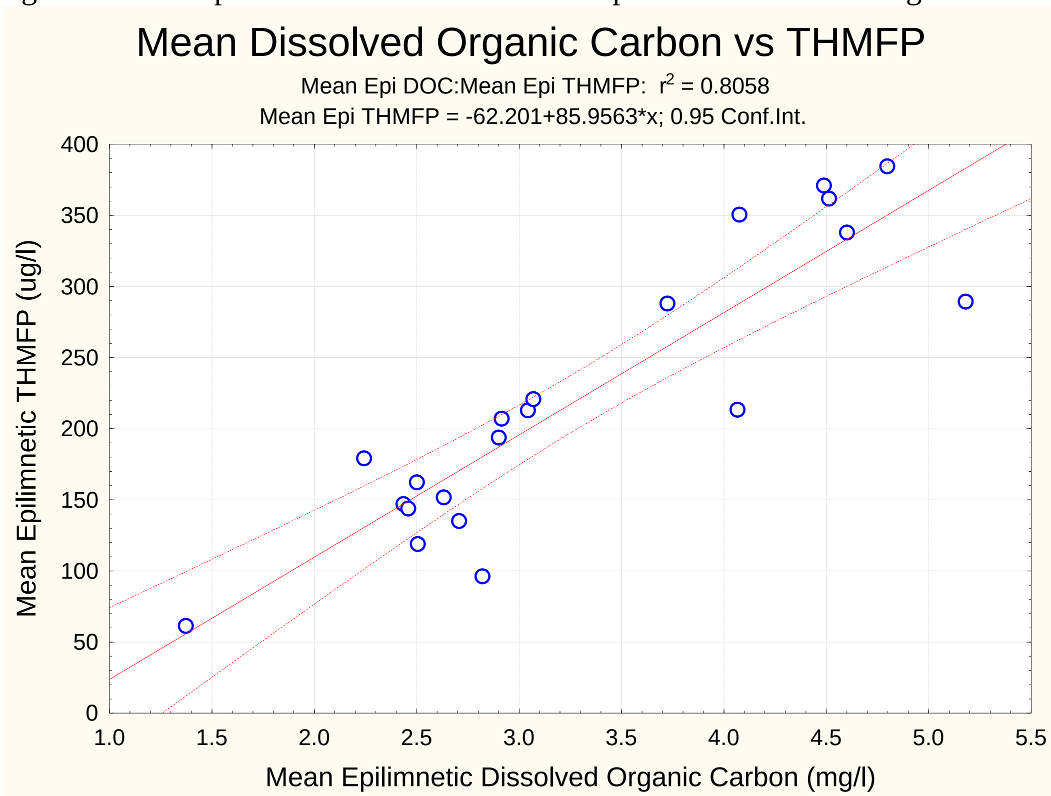

Figure 4: Mean epilimnetic THMFP and mean epilimnetic total phosphorus

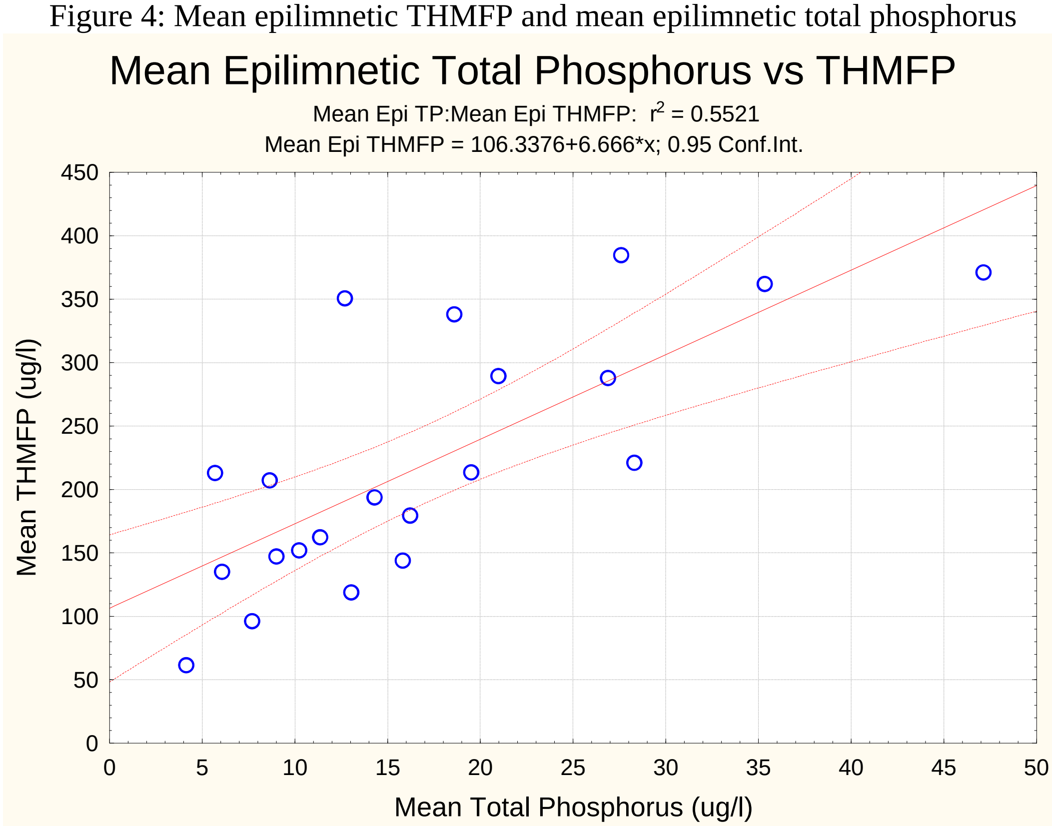

Figure 5: Mean epilimnetic THMFP and mean epilimnetic chlorophyll a.

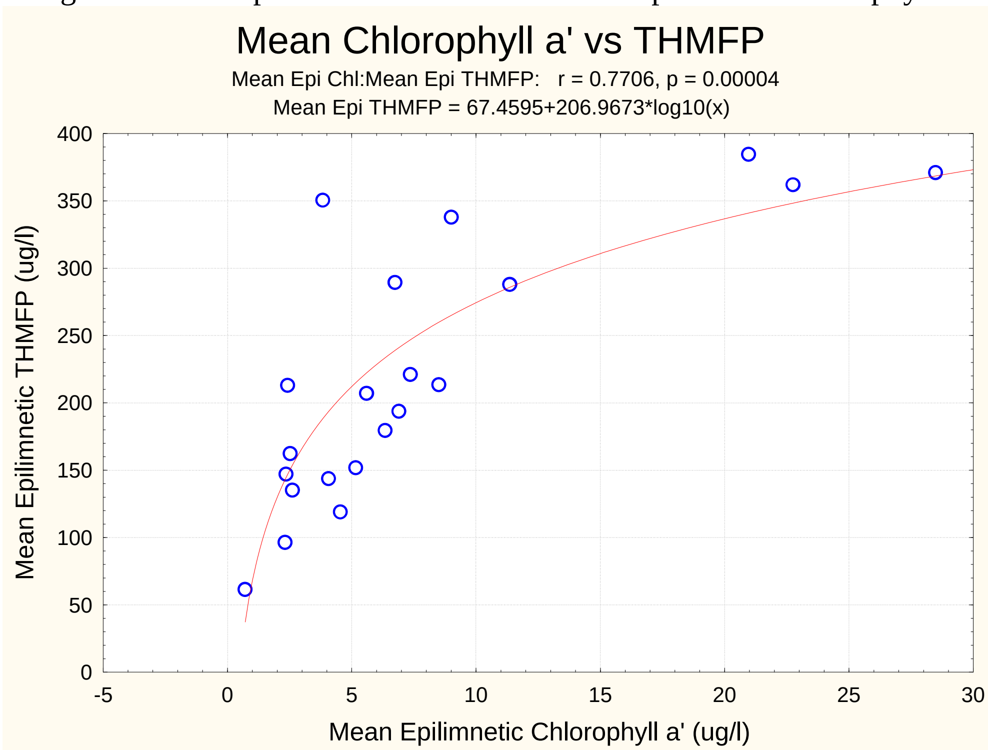

Figure 6: Water Treatment Plant Mean TTHM